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THE OXYGEN UPTAKE DEMAND OF RESUSPENDED BOTTOM SEDIMENTS

Seattle University

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THE OXYGEN UPTAKE DEMAND OF RESUSPENDED BOTTOM SEDIMENTS

by

Seattle University
Seattle, Washington

for the

WATER QUALITY OFFICE
ENVIRONMENTAL PROTECTION AGENCY

Program No. 16070 DCD
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ABSTRACT

A laboratory study has been conducted to show the application of the Warburg respirometer in evaluating the influence of light, NaCl, dilution salts, temperature and agitation on the maximum oxygen uptake rate of disturbed bottom deposits. Experiments were conducted on estuarian benthic material obtained from Bellingham Bay, Washington.

In all experiments the initial oxygen uptake rate was the maximum uptake rate. Results obtained using distilled water as the suspending medium were not appreciably altered due to the addition of B.O.D. dilution salts, or NaCl in concentrations less than 30,000 mg/ℓ. The initial uptake rate also appears to be insensitive to light.

Ambient temperatures were varied from 10°C to 20°C and agitation settings were varied from instrument maximum to twenty-five percent of maximum. The Squalicum Creek sample showed variations in initial uptake from 1,956 to 56,760 mg/ℓ of oxygen per hour. The Whatcom Creek sample had a range of from 2,784 to 83,040 mg/ℓ of oxygen per hour.

Results indicate that the maximum uptake rate is very sensitive to temperature, degree of disturbance, and the total volatile solids concentration of the benthic material.

Agitation alone was shown to account for at least a ten fold increase in the maximum oxygen demand.

This report is submitted in fulfillment of Project 16070 DCD, Contract No. 14-12-481 between the Water Quality Office and Seattle University.

Key Words: Benthic sludge, Warburg respirometer, B.O.D., estuaries, dissolved oxygen, sediment, Bellingham Bay, sludge.

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SECTION I

CONCLUSIONS

1. The oxygen demand of resuspended bottom sediments can be determined by using the Warburg respirometer. The instrument is especially useful for determining maximum oxygen uptake rates.

2. The magnitude of the maximum oxygen uptake rate is sensitive to the elapsed storage time of the samples. Storage at $4^{o}C$ does not eliminate this problem.

3. The bottom sediments tested in this study did not require external seeding to initiate the biochemical reaction. No lag phases were encountered in any of the experiments.

4. Distilled water was used as the suspending medium in this study. Maximum oxygen uptake rates were not changed when the suspending medium was modified by introducing NaCl (concentrations up to 30,000 mg/ℓ) or B.O.D. dilution salts.

5. Maximum oxygen uptake rates of bottom sediments do not appear to be light sensitive.

6. The magnitude of the initial oxygen uptake rate is sensitive to temperature and degree of agitation.

7. Suspension can increase the quiescent, maximum oxygen uptake rate by more than a multiple of ten.

SECTION II

RECOMMENDATIONS

This investigation has demonstrated that the oxygen demand of resuspended bottom sediments is different than those noted while the material remains quiescent. Of particular interest is the fact that uptake rates observed in the suspended state are exceedingly high compared to observed quiescent rates.

The oxygen demand rate of disturbed bottom sediments could significantly affect the dissolved oxygen concentration of estuaries during periods of dredging. This phenomena would be particularly serious in estuaries where tidal action promotes suspension for prolonged time periods.

Any anticipated dredging operation should be preceded by efforts to determine the resulting effect on ambient oxygen concentrations. The Warburg respirometer and the methods outlined in this study provide a means for approaching the problem. At the very least, the Warburg approach can be used to anticipate the maximum and minimum effects on estuarian oxygen concentration due to dredging operations.

SECTION III

INTRODUCTION

The influence of biochemical oxygen demand (B.O.D.) on ambient oxygen concentration has long been a subject of interest to environmentalists concerned with obtaining a more comprehensive knowledge of the dissolved oxygen problem. Recent literature has indicated a revived interest in the effect of benthic B.O.D. on the oxygen concentration of the overlying water.

The removal of oxygen due to the microbial respiration of benthal deposits has been recognized for many years (1) (2). In principle the mode of oxygen removal by benthic deposits is caused by one, or a combination of, the following.

1. B.O.D. may be introduced from the benthal deposits by scour (3) (4).
2. Oxygen may be consumed by the gases which are produced by anaerobic decomposition and rise from the benthal layers (5) (6) (7) (8).
3. Oxygen may be consumed by the soluble end products of benthal decomposition which diffuse into the overlying water (5) (9).
4. The oxygen demand of the sludge itself.

Many studies have been made in an effort to identify the prime variables which might affect the rate of benthal decomposition. Investigators have studied the possible influence of: (a) light, (b) salinity, (c) sludge depth, (d) oxygen concentration in the overlying water, and (3) season and temperature.

Recent work by Hanes (10) has indicated that the benthal oxygen uptake rate is independent of oxygen concentration. Subsequent work by McDonnel (11) indicates that oxygen uptake rates are indeed dependent on the overlying oxygen concentration. The controversy is whether or not the oxygen uptake is controlled by the rate of transport of oxidizable materials from the interior of the deposits to the overlying water or by the rate of diffusion of oxygen into the deposit.

Other work by Hanes (12) suggests that the oxygen uptake rate of a benthal system increases with increased concentrations of sea water, and also increases with the addition of B.O.D. nutrients to the system.

Oldaker (13) indicates that the benthic oxygen demand varies with sludge depth. His work also suggests the importance of benthic nitrification to the oxygen budget.

The maximum oxygen uptake rate has been used by both Hanes and McDonnell to evaluate the influence of temperature, sea water and added nutrients on the oxygen demand of bottom deposits. Both investigators have expressed oxygen uptake in units of mass per area per hour. The area concept is poor. It does not permit the results of different investigators to be compared.

Past studies conducted to determine the oxygen demand of benthic

materials have been designed so that the sediment remains stationary, while the overlying water has an induced velocity gradient. It is obvious that bottom sediments are frequently resuspended by flood flows, dredging and scouring action. The question is raised, "does the increased surface area, caused by resuspension, create an oxygen demand significantly exceeding that observed in the quiescent situation?" If resuspension is a significant factor the act of dredging might seriously affect ambient oxygen concentrations in many estuaries. A survey of the literature suggests that this aspect of the benthic problem has not received attention.

It is the purpose of this paper to evaluate the use of the Warburg apparatus in determining the oxygen uptake demand of disturbed bottom deposits and to determine if resuspension significantly alters the oxygen demand rate of benthic material.

SECTION IV

NATURE AND SCOPE

The purpose of this investigation is to examine the oxygen uptake rate of resuspended estuarian bottom sediments. Particular interest is directed toward observing the change in magnitude of the maximum uptake rate due to changes in ambient temperature, NaCl concentration, and the presence of B.O.D. dilution salts, while the benthic material is exposed to various states of agitation. These parameters are selected for study because of their possible influence on the rate of oxygen depletion in estuaries due to the resuspension of bottom sediments during periods of intense dredging.

The Warburg apparatus was chosen as the instrument best suited for this study. The number of simultaneous experiments which can be run on the instrument provides a good capacity for exposing several replicas to parametric variations. The instrument also has excellent thermal control, a means for varying agitation and an illumination system for light and dark studies.

Bottom samples used during the study were collected from Bellingham Bay on January 14, 1969, and on March 21, 1969. This sampling site was selected because information made available by F.W.Q.A. (14) indicates that the Whatcom Creek and Squalicum Creek areas of Bellingham Bay contain extensive bottom deposits capable of exerting high biochemical oxygen demands. Bellingham Bay, being only a ninety minute drive from the laboratory, provided both a convenient and significant sampling site.

The oxygen uptake of these samples is studied using three suspending mediums: distilled water, B.O.D. dilution water and salt suspensions up to 30,000 mg/ℓ of NaCl. Ambient temperatures are varied from 10°C to 20°C. Agitation is accomplished by varying the eccentricity setting of the Warburg cam. The entire eccentricity range has been observed. The possible influence of light on the oxygen uptake profile has also been examined.

SECTION V

METHODS AND INSTRUMENTATION

SAMPLE STORAGE

Sludge samples were returned to the laboratory within twelve hours of collection. Bottom material was retained in polyethylene containers and stored at 4°C until required for testing.

DILUTION MEDIUMS

There were three basic dilution or suspending mediums used during the test sequence.

Distilled Water - Distilled water was obtained from a standard, single-stage distilling apparatus.

Sodium Chloride - Sodium chloride suspensions were made by dissolving the required weight of sodium chloride crystals (reagent grade) in distilled water.

Dilution Water - Standard dilution water was used as described in Standard Methods (15) under the section discussing procedure for testing biochemical oxygen demand.

THE WARBURG APPARATUS

A Gilson (RWBP 3) Warburg apparatus was used during this study. This instrument is refrigerated and is equipped with a bank of 30 watt reflector spotlights for light and dark studies. Temperature is controlled to within $\pm$ 0.05°C.

The reaction vessels have a 125 ml capacity. Brodie solution was used as the manometric fluid and a 10% KOH solution was used in the center well to absorb carbon dioxide.

Flask calibration constants were obtained using the mercury method.

There are two settings on the instrument which determine the degree of flask agitation. The first is the number of shaft revolutions per minute. This variable was fixed during the entire test series at 110 revolutions per minute. The second is the cam or amplitude setting which is controlled by a set screw. The degree of eccentricity was set in four equal steps from minimum to maximum. In this report the set screw positions are referred to as 25, 50, 75 and 100 percent maximum amplitude.

WARBURG TEST PROCEDURE

One of the prime variables which has to be determined for each test run was a measure of the sludge concentration in the reaction

vessels. The magnitude of this variable was calculated by making a series of dilutions using wet sludge. The concentration range on a set sludge basis varied from 10,000 to 100,000 mg/ℓ. Portions of these mixtures were subjected to a total volatile solids analysis, and the final sludge concentration was recorded in mg/ℓ of total volatile solids (T.V.S.).

A 30 c.c. syringe, without needle, was found to be the most efficient and reproducible method of introducing the material into the reaction vessel. The entire 30 c.c. volume was placed in the vessel.

When conducting a Warburg run, the instrument was allowed sufficient time to reach thermal equilibrium before the reaction vessels were placed on the manometer stems.

LIGHT AND DARK STUDIES

Several experiments were run during the test sequence to determine if the presence of light significantly influenced the rate of oxygen uptake. When these tests were conducted, replica reaction vessels were placed on the manometer stems. One flask was wrapped in two layers of aluminum foil while the other was left unmodified.

SECTION VI

RESULTS AND DISCUSSION

The results presented in this section reflect oxygen uptake studies conducted on bottom deposits obtained from Bellingham Bay. Samples were collected at the mouth of Squalicum Creek and Whatcom Creek. All analyses were made using facilities at Seattle University.

SQUALICUM CREEK SLUDGE

Samples were taken at the Squalicum Creek station on January 14, 1969, and on May 20, 1969. Warburg studies were conducted at several temperatures and agitation settings using distilled water and NaCl solutions as dilution media. Samples were also subjected to light and dark studies to determine if light significantly influenced reaction kinetics.

Distilled Water as a Dilution Medium - Warburg studies for both Squalicum Creek samples suggest that the initial biochemical reaction can be approximated by first order kinetics when distilled water is used as the suspending medium.

For purposes of this paper, the first order solution is defined as:

$$y = L_{ULT} [1 - 10^{-kt}],$$

where,

y = oxygen consumed during elapsed time "t" in mg/ℓ,

L_{ULT} = ultimate first stage oxygen demand in mg/ℓ,

k = reaction constant in $hours^{-1}$,

t = elapsed time in hours.

Figure Number 1 is a typical Warburg study conducted on the first Squalicum Creek sample, using an agitated and unagitated flask. Note the substantially reduced oxygen uptake profile for the Warburg flask that was not agitated.

The Thomas method (1) was used to calculate k and L_{ULT}. The maximum oxygen uptake rate is defined as:

$$\frac{dy}{dt_o} = 2.3\ k\ L_{ULT},$$

and is expressed in mg/ℓ per hour.

The second Squalicum Creek sample was subjected to Warburg studies

using ambient temperatures of 10°C, 15°C and 20°C. Figure Number 2 is a typical run showing replica oxygen uptake profiles.

Table Number 1 is a tabulation of the ultimate first stage oxygen demand as a function of temperature and amplitude setting. Table Number 2 is a two way classification of the slope coefficients given in Table Number 1. Statistical analysis using the F-test at the 99th percentile indicates that the ultimate first stage B.O.D. for the Squalicum creek sample is independent at temperature and amplitude setting.

The mean value of L_{ULT} is 22.6 C_B and the associated standard deviation is 3.2 C_B. The coefficient of variation for the data is approximately fourteen percent.

Table Number 3 is a summary of data relating maximum oxygen uptake rate and the total volatile solids concentration of Squalicum sludge. For a given concentration of T.V.S., the magnitude of the maximum oxygen uptake rate appears to depend on both the ambient temperature and the amplitude setting.

Figure Number 3 indicates how the amplitude setting influences the magnitude of $\frac{dy}{dt_o}$ for fixed ambient temperatures.

Figure Number 4 indicates an insignificant change in the initial O_2 uptake curve during storage at 4°C. This is a very important point, because any change during storage would require that all measurements be adjusted for elapsed storage time.

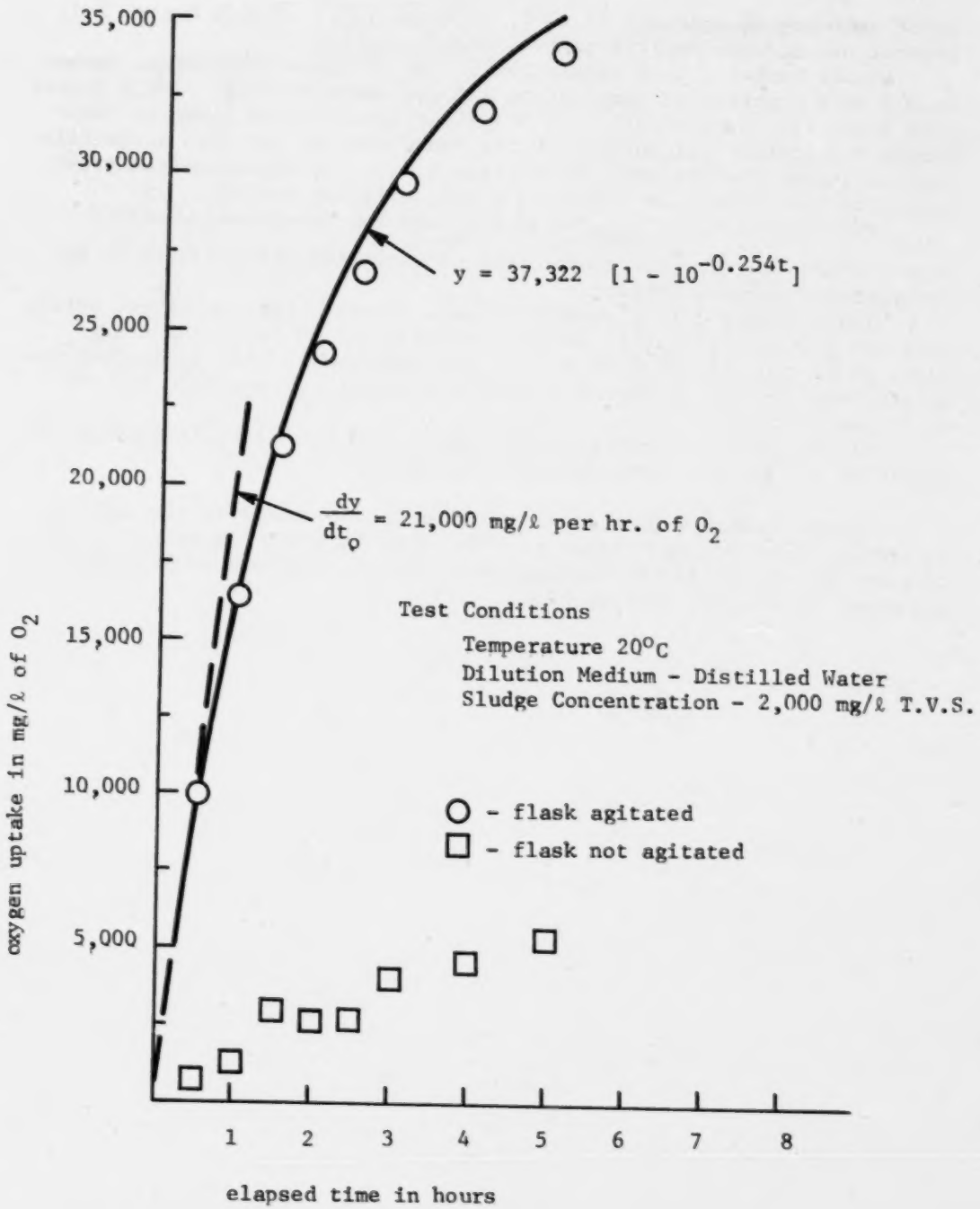

Figure No. 1 - Oxygen Uptake Study for the First Squalicum Creek Sample.

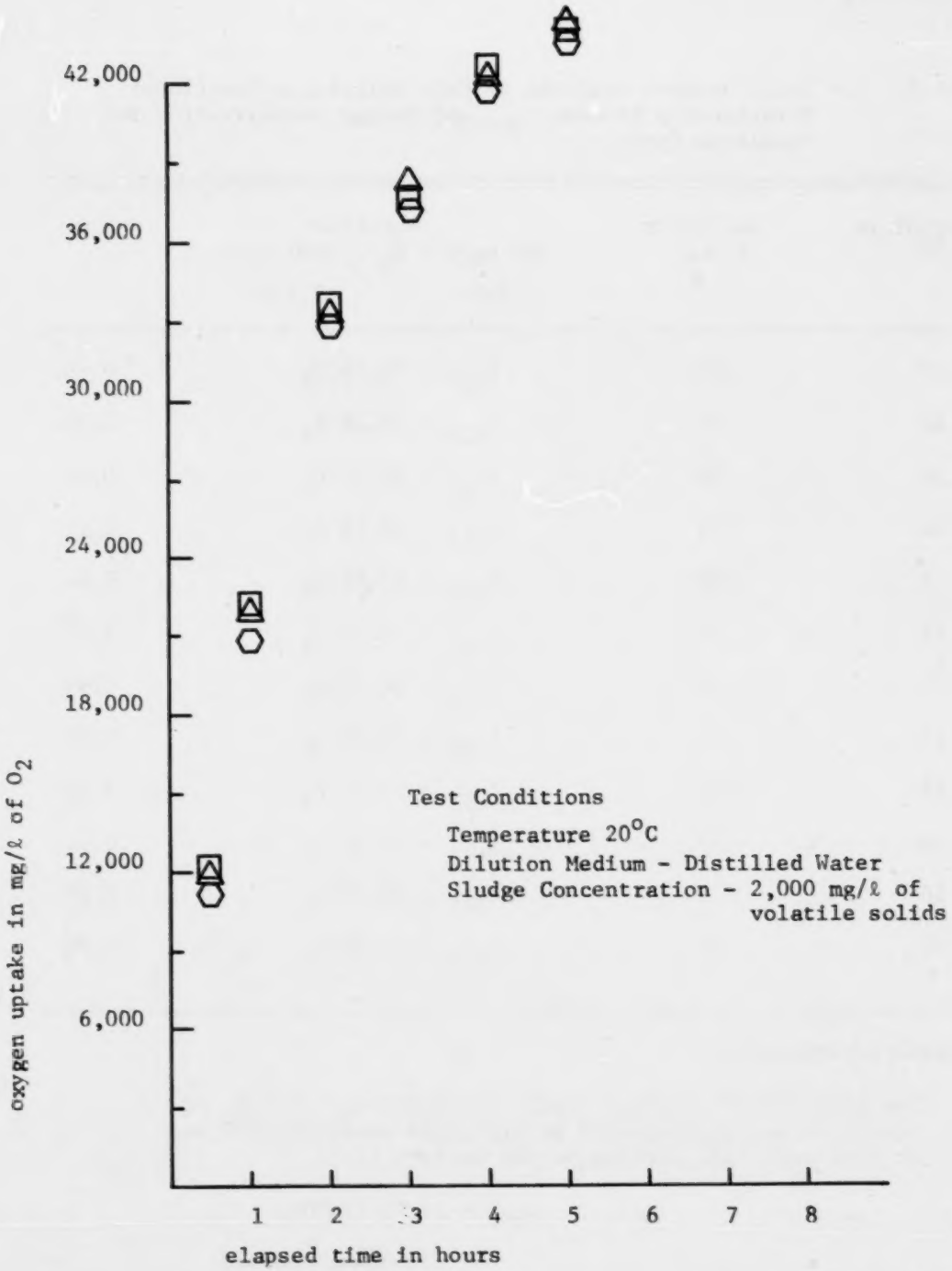

Figure No. 2 - Replica Agreement for the Second Squalicum Creek Sample.

Table No. 1 - Least Squares Analysis of Data Defining A Functional Relationship between L_{ULT} and Sludge Concentration for Squalicum Creek.

Temperature ^{o}C	Amplitude % Max.	Function 400 mg/ℓ < C_B < 4000 mg/ℓ T.V.S.	r
20	100	$L_{ULT} = 26.78\ C_B$	0.99
20	75	$L_{ULT} = 19.16\ C_B$	0.99
20	50	$L_{ULT} = 25.59\ C_B$	0.99
20	25	$L_{ULT} = 19.28\ C_B$	0.99
15	100	$L_{ULT} = 22.02\ C_B$	0.99
15	75	$L_{ULT} = 18.45\ C_B$	0.99
15	50	$L_{ULT} = 26.42\ C_B$	0.99
15	25	$L_{ULT} = 18.80\ C_B$	0.99
10	100	$L_{ULT} = 23.21\ C_B$	0.99
10	75.	$L_{ULT} = 23.09\ C_B$	0.99
10	50	$L_{ULT} = 26.78\ C_B$	0.99
10	25	$L_{ULT} = 21.90\ C_B$	0.99

Illustrative Example:

The expected first stage B.O.D. for 2,000 mg/ℓ T.V.S. of Squalicum sludge suspended in distilled water at 20°C and at full amplitude setting on the Warburg is:

$$L_{ULT} = 26.78\ (2{,}000)$$

$$= 53{,}560\ mg/\ell\ of\ O_2$$

Table No. 2 - Two Way Classification for Slope Coefficients Used To Relate L_{ULT} and C_B

Temperature °C	Amplitude in % Maximum				Temperature Mean
	25	50	75	100	$\bar{X}_{i\cdot}$
20	19.28	25.59	19.16	26.78	22.70
15	18.80	26.42	18.45	22.02	21.42
10	21.90	26.78	23.09	23.21	23.75
Amplitude Mean $\bar{X}_{\cdot j}$	19.99	26.26	20.23	24.00	22.62 General Mean $\bar{X}$

Table No. 3 - Least Squares Analysis of Data Defining A Functional Relationship Between Maximum Oxygen Uptake Rate And Sludge Concentration for Squalicum Creek

Temperature °C	Amplitude % Max.	Function 400 mg/ℓ < C_B < 4000 mg/ℓ T.V.S.	r
20	100	$\frac{dy}{dt_o} = 14.19\ C_B$	0.99
20	75	$\frac{dy}{dt_o} = 9.77\ C_B$	0.99
20	50	$\frac{dy}{dt_o} = 11.80\ C_B$	0.99
20	25	$\frac{dy}{dt_o} = 6.32\ C_B$	0.99
15	100	$\frac{dy}{dt_o} = 11.32\ C_B$	0.99
15	75	$\frac{dy}{dt_o} = 8.82\ C_B$	0.99
15	50	$\frac{dy}{dt_o} = 11.09\ C_B$	0.99
15	25	$\frac{dy}{dt_o} = 4.53\ C_B$	0.99
10	100	$\frac{dy}{dt_o} = 8.58\ C_B$	0.99
10	75	$\frac{dy}{dt_o} = 8.23\ C_B$	0.99
10	50	$\frac{dy}{dt_o} = 8.11\ C_B$	0.99
10	25	$\frac{dy}{dt_o} = 4.89\ C_B$	0.99

Illustrative Example:

The expected maximum oxygen uptake rate for 2,000 mg/ℓ T.V.S. of Squalicum Creek sludge suspended in distilled water at 20°C and at fall amplitude setting on the Warburg is:

$$\frac{dy}{dt_o} = 14.19\ (2{,}000)$$

$$= 28{,}380 \text{ mg of } O_2 \text{ per liter per hour}$$

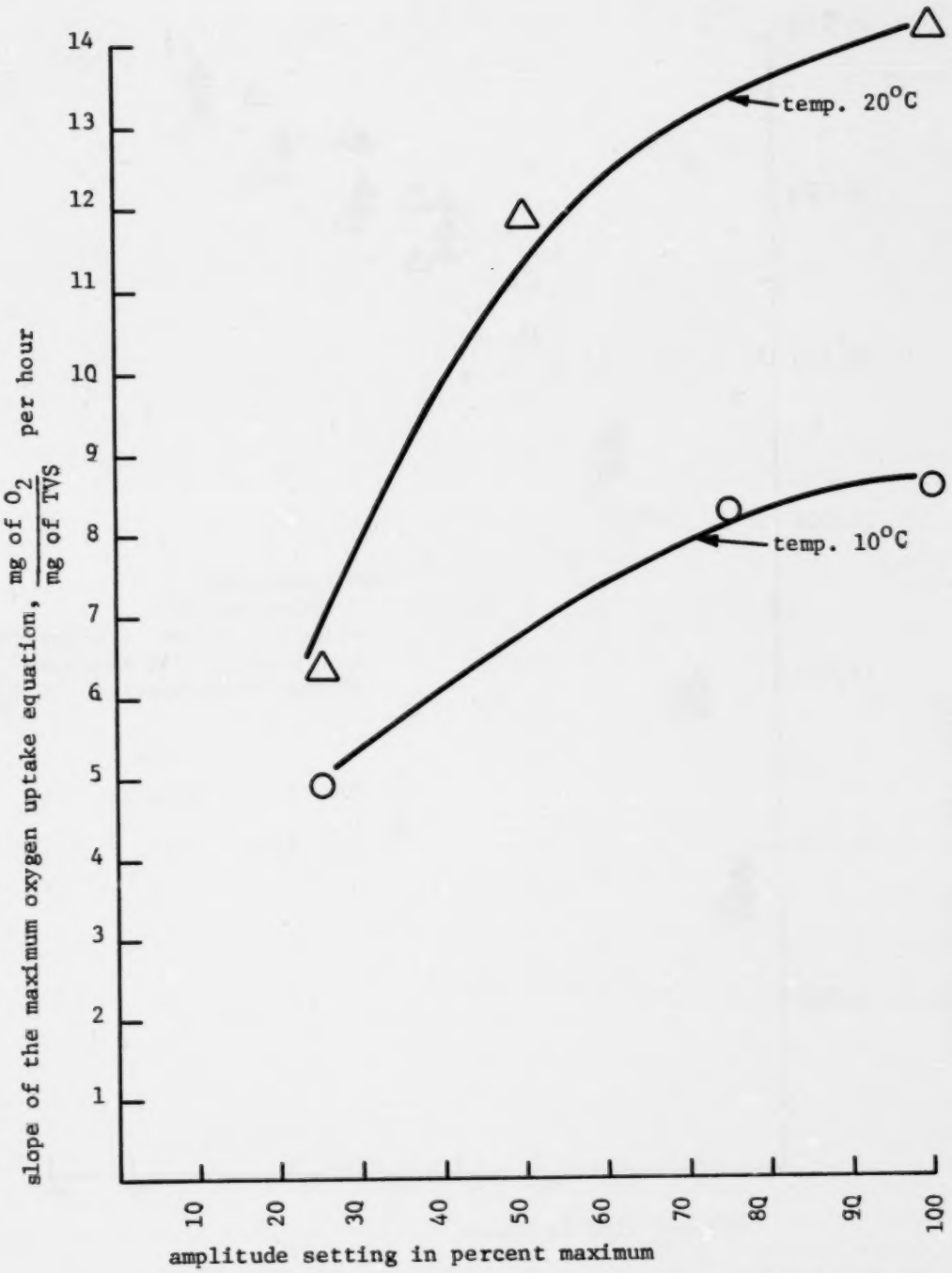

Figure No. 3 - Enveloping Curves Showing Variations in Maximum Oxygen Uptake as a Function of Temperature and Amplitude Setting for Squalicum Sludge.

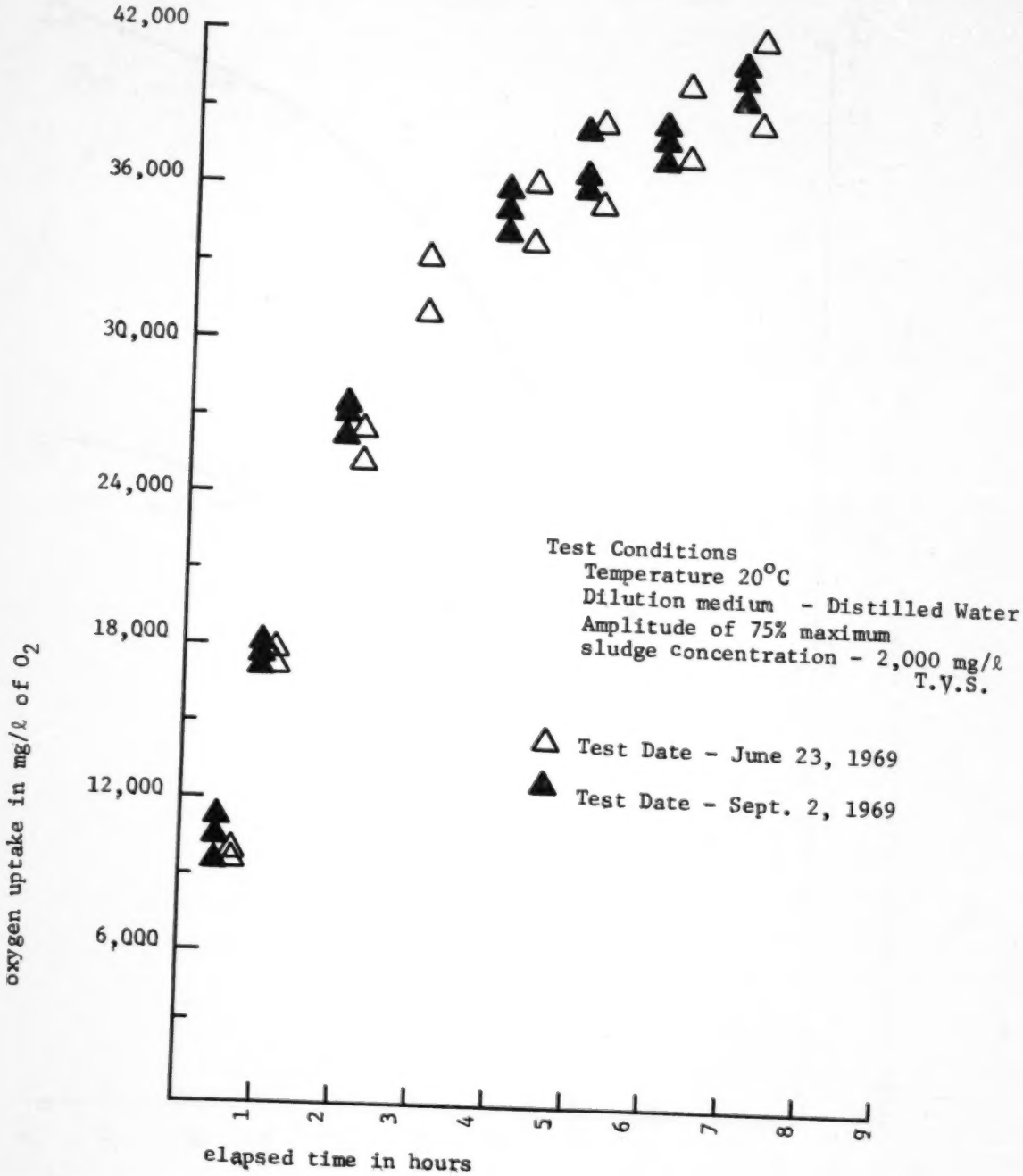

Figure No. 4 - Oxygen Uptake Study, Squalicum Creek.

Sodium Chloride Solution as a Dilution Medium - Experiments were conducted to determine if the oxygen uptake profile would be significantly altered by the presence of varying concentrations of sodium chloride.

The results of a typical experiment are shown in Figure Number 5. The amount of oxygen consumed during the test period is greater for the salt medium than for the distilled water medium. However, the initial uptake rate is essentially independent of sodium chloride concentration up to 30,000 mg/ℓ.

Figure Number 6 is a comparison of two long term Warburn experiments. The long term oxygen uptake profiles are influenced by the presence of sodium chloride and the shaking rate.

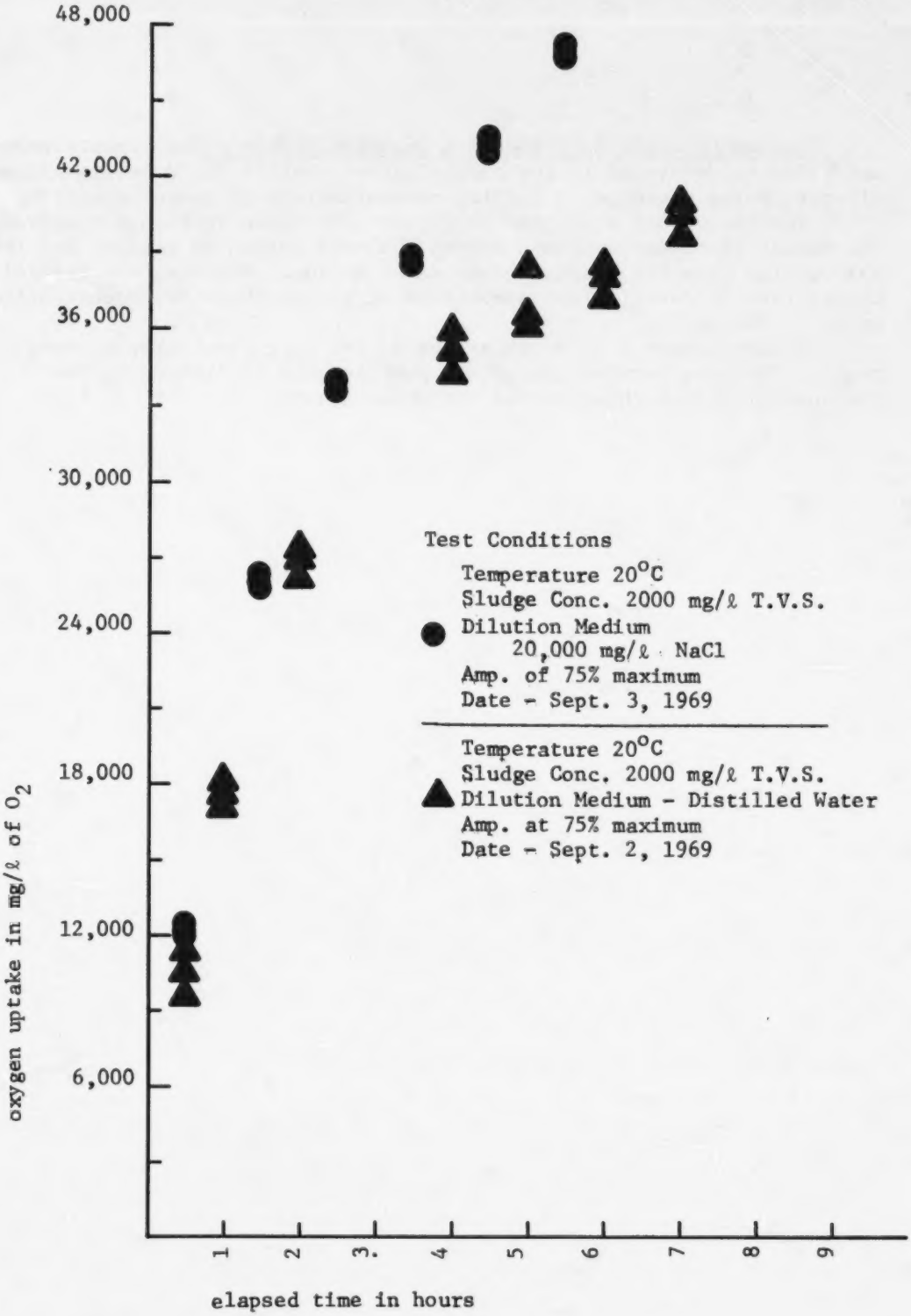

Figure No. 5 - Oxygen Uptake Test on Squalicum Sludge Using Distilled Water and Sodium Chloride as Dilution Mediums.

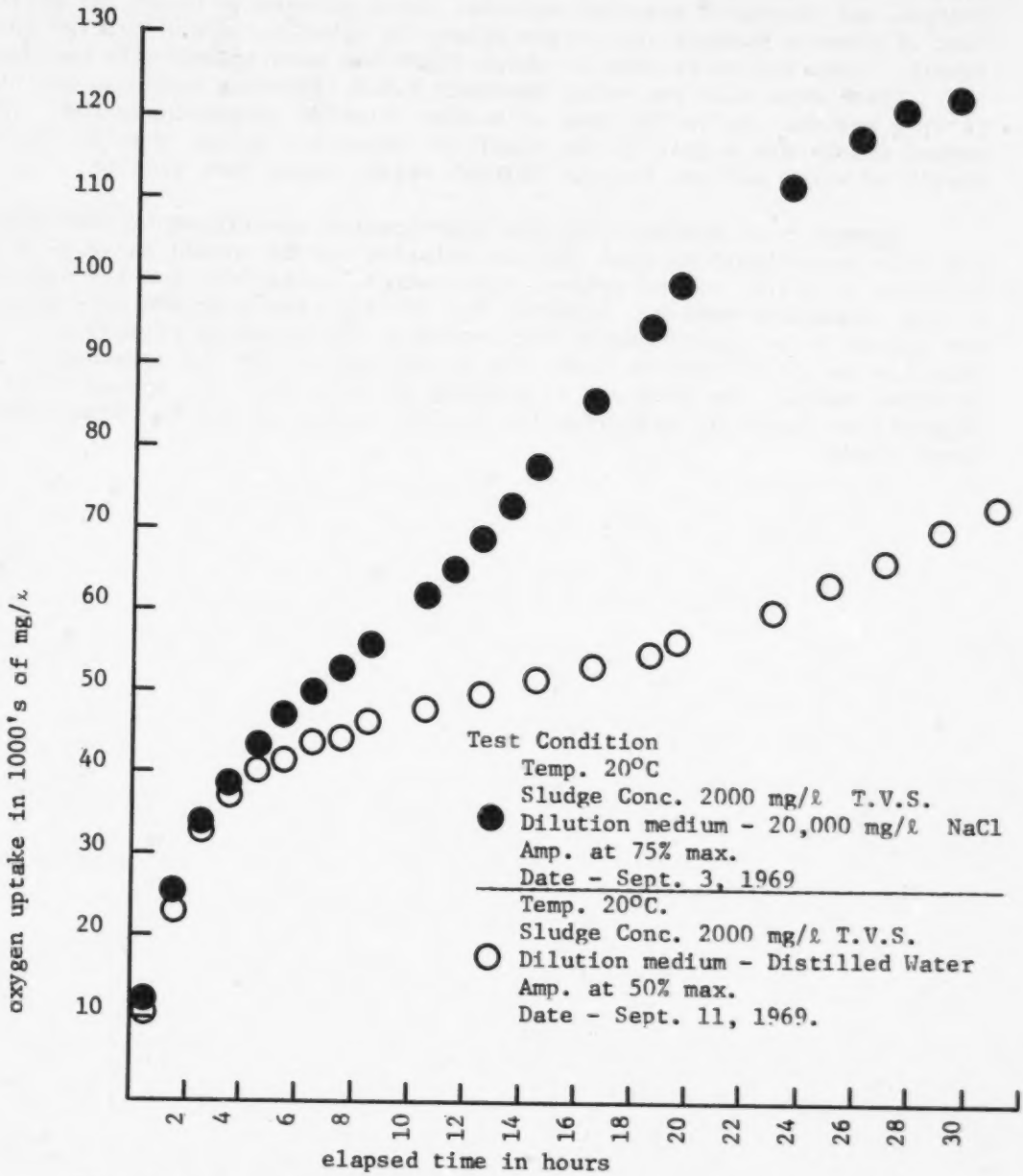
oxygen uptake in 1000's of mg/ℓ
elapsed time in hours
Test Condition
Temp. 20°C
Sludge Conc. 2000 mg/ℓ T.V.S.
Dilution medium - 20,000 mg/ℓ NaCl
Amp. at 75% max.
Date - Sept. 3, 1969
Temp. 20°C.
Sludge Conc. 2000 mg/ℓ T.V.S.
Dilution medium - Distilled Water
Amp. at 50% max.
Date - Sept. 11, 1969.

Figure No. 6 - Long Term Oxygen Uptake Analysis for Squalicum Creek Sludge Using Sodium Chloride and Distilled Water as Dilution Mediums.

Light and Dark Tests - Figure Number 7 is a typical plot of data obtained from Warburg studies where replica runs were made using foil wrapped and unwrapped reaction vessels. There appears to be an insignificant difference between the oxygen uptake in vessels exposed to high intensity light and those vessels where light has been essentially excluded.

Tests were also run using standard B.O.D. dilution water as the suspending medium. As in the case of sodium chloride suspensions, the oxygen uptake was higher in the modified suspension medium than in the distilled water medium, but the initial uptake rates were similar.

Comment - It appears, for the experimental conditions imposed during this investigation, that the accumulative oxygen uptake curve is a function of T.V.S. concentration, temperature, agitation, and the nature of the suspending medium. However, the initial oxygen uptake rate does not appear to be significantly influenced by the presence of sodium chloride in concentrations less than 30,000 mg/ℓ or by the presence of dilution salts. The presence or absence of light does not appear to be a significant factor in measuring the initial oxygen uptake for Squalicum Creek sludge.

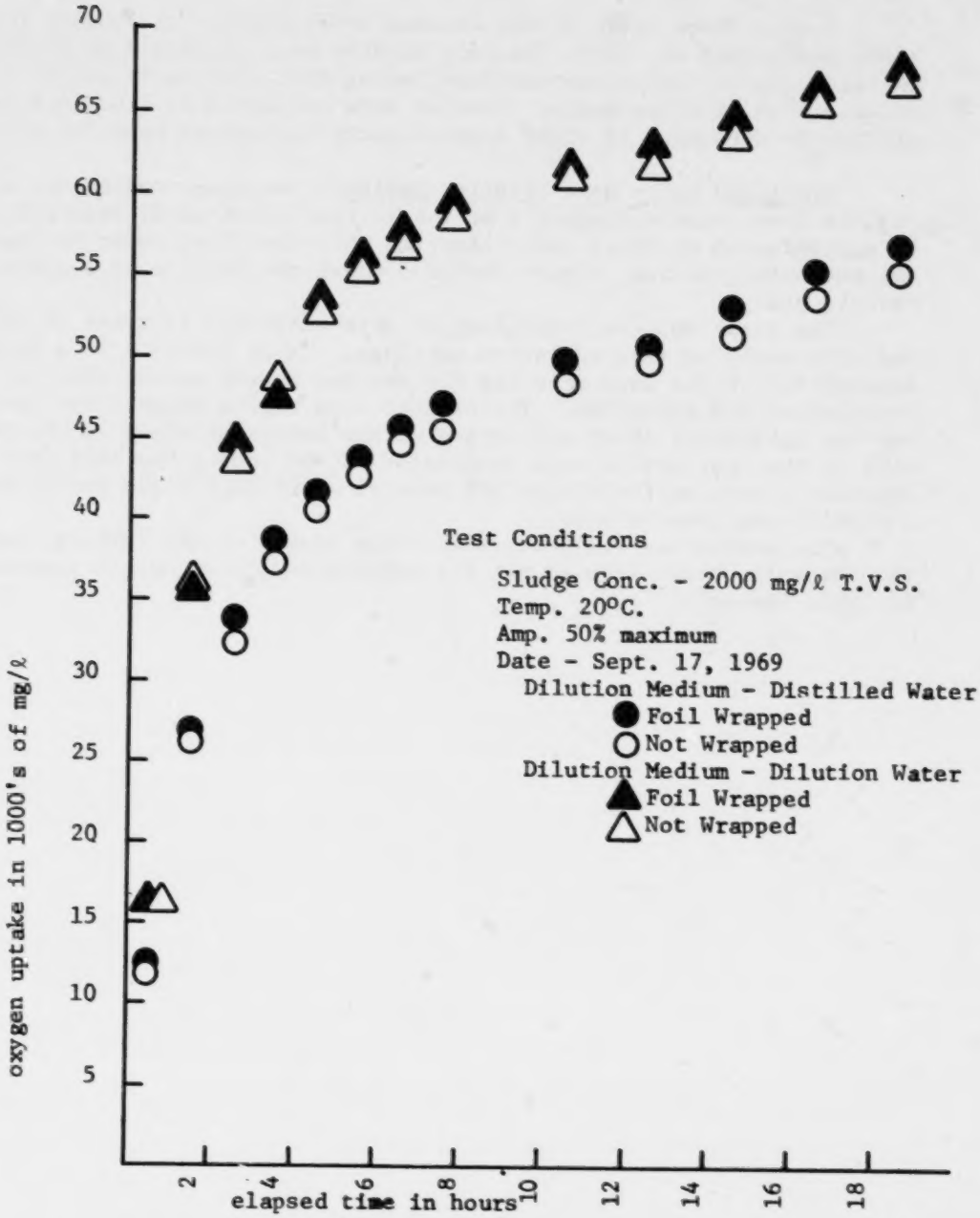

Figure No. 7 - Light and Dark Oxygen Uptake Tests on Squalicum Sludge Using Distilled Water and Standard B.O.D. Dilution Water as Suspending Medium.

WHATCOM CREEK SLUDGE

Samples were taken at the Whatcom Creek Station on January 14, 1969, and on May 20, 1969. Warburg studies were conducted at several temperatures and agitation settings, using distilled water and NaCl solutions as dilution media. Samples were subjected to light and dark studies to determine if light significantly influenced reaction kinetics.

Distilled Water as a Dilution Medium - Warburg studies for the Whatcom Creek sample suggest that the initial biochemical reaction can be approximated by first order kinetics when distilled water is used as the suspending medium. Figure Number 8 shows the results of a typical Warburg study.

The first Whatcom Creek samples were subjected to tests at 20°C and 10°C using several agitation settings. Table Number 4 is a least squares fit of the data relating the maximum oxygen uptake rate to temperature and agitation. The elapsed time during which these tests were run was relatively short and oxygen uptake curves obtained at the beginning of the test period were duplicated at the end of the test period. Apparently storing the sludge for several weeks at 4°C did not produce a significant interference.

The second Whatcom Creek sample was tested on the Warburg, and the resulting least squares fit for maximum oxygen uptake is presented in Table Number 5.

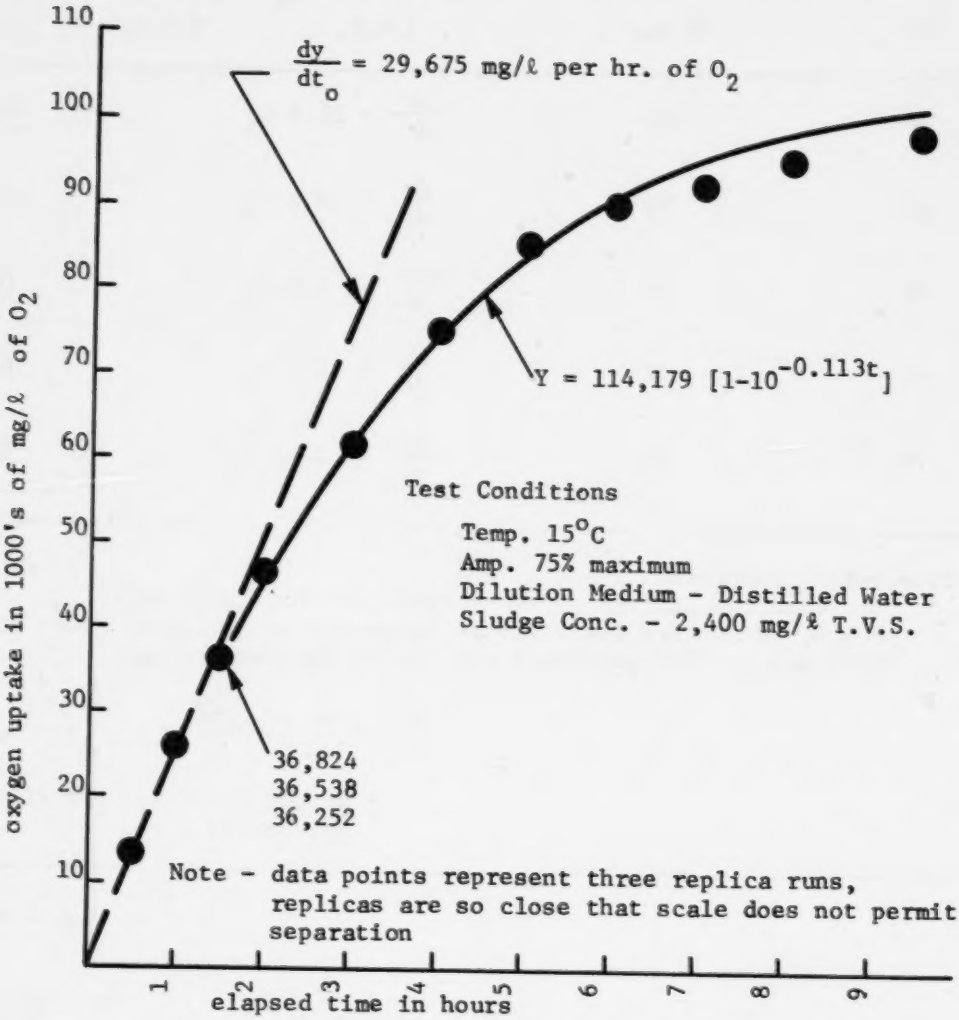

Figure No. 8 - Oxygen Uptake Study for the First Whatcom Creek Sample.

Table Number 4 - Least Squares Analysis of Data Defining a Functional Relationship Between Maximum Oxygen Uptake Rate and Sludge Concentration for the First Whatcom Creek Sample

Temperature	Amplitude	Function 480 mg/ℓ < C_B < 4800 mg/ℓ T.V.S.	r
^{o}C	% Max.		
20	100	$\frac{dy}{dt_o} = 21.8\ C_B$	0.99
20	50	$\frac{dy}{dt_o} = 18.2\ C_B$	0.99
20	25	$\frac{dy}{dt_o} = 9.9\ C_B$	0.99
10	75	$\frac{dy}{dt_o} = 10.2\ C_B$	0.99
10	25	$\frac{dy}{dt_o} = 9.46\ C_B$	0.99

Illustrative Example:

The expected maximum oxygen uptake rate for 2,400 mg/ℓ T.V.S. of Whatcom Creek sludge suspended in distilled water at 20°C and at 75°C amplitude setting on the Warburg is:

$$\frac{dy}{dt_o} = 20\ (2{,}400)$$

= 48,000 mg of O_2 per liter per hour.

Table Number 5 - Least Squares Analysis of Data Defining A Functional Relationship Between Maximum Oxygen Uptake Rate and Sludge Concentration for the Second Whatcom Creek Sample

Temperature ^{o}C	Amplitude % Max.	Function 480 mg/ℓ < C_B < 4800 mg/ℓ T.V.S.	r
20	100	$\frac{dy}{dt_o} = 17.3\ C_B$	0.99
20	75	$\frac{dy}{dt_o} = 15.4\ C_B$	0.99
20	50	$\frac{dy}{dt_o} = 14.0\ C_B$	0.99
20	25	$\frac{dy}{dt_o} = 10.0\ C_B$	0.99
15	100	$\frac{dy}{dt_o} = 12.0\ C_B$	0.99
15	75	$\frac{dy}{dt_o} = 12.6\ C_B$	0.99
15	50	$\frac{dy}{dt_o} = 11.4\ C_B$	0.99
15	25	$\frac{dy}{dt_o} = 9.5\ C_B$	0.99
10	100	$\frac{dy}{dt_o} = 10.0\ C_B$	0.99
10	75	$\frac{dy}{dt_o} = 9.3\ C_B$	0.99
10	50	$\frac{dy}{dt_o} = 8.1\ C_B$	0.99
10	25	$\frac{dy}{dt_o} = 5.8\ C_B$	0.99

Illustrative Example: See Table Number 3.

Several months elapsed during this series of tests. The ultimate first order B.O.D. did significantly change during this period. To compensate for the storage factor, all data were adjusted to agree with the data obtained at the beginning of the test period. The data in Table Number 5 have been adjusted.

Table Number 4 and Table Number 5 indicate for a fixed C_B that the initial oxygen uptake is sensitive to both temperature and agitation. This observation is graphically illustrated in Figure Number 9. If the data of Table Number 4 were plotted on this graph, different curves would appear for the $20^{\circ}C$ and $10^{\circ}C$ temperature setting. This apparent inconsistency is readily explained by the fact that storage time for the Whatcom Creek sample plays an important role in determining the magnitude of $\frac{dy}{dt_o}$. Since the two Whatcom samples were stored for different periods of time before testing, the absolute magnitudes of $\frac{dy}{dt_o}$ should differ, but the relative influence of temperature and agitation should be, and is, similar.

When the first order ultimate demand (L_{ULT}) was calculated from the data of the first Whatcom Creek sample, it is found that the lower thermal environment ($10^{\circ}C$) yields an L_{ULT} about fourteen percent lower than that observed at the higher thermal environment ($20^{\circ}C$). A similar analysis for the second Whatcom Creek sample yielded an eleven percent difference. No such dependency between L_{ULT} and temperature was observed for the Squalicum Creek samples.

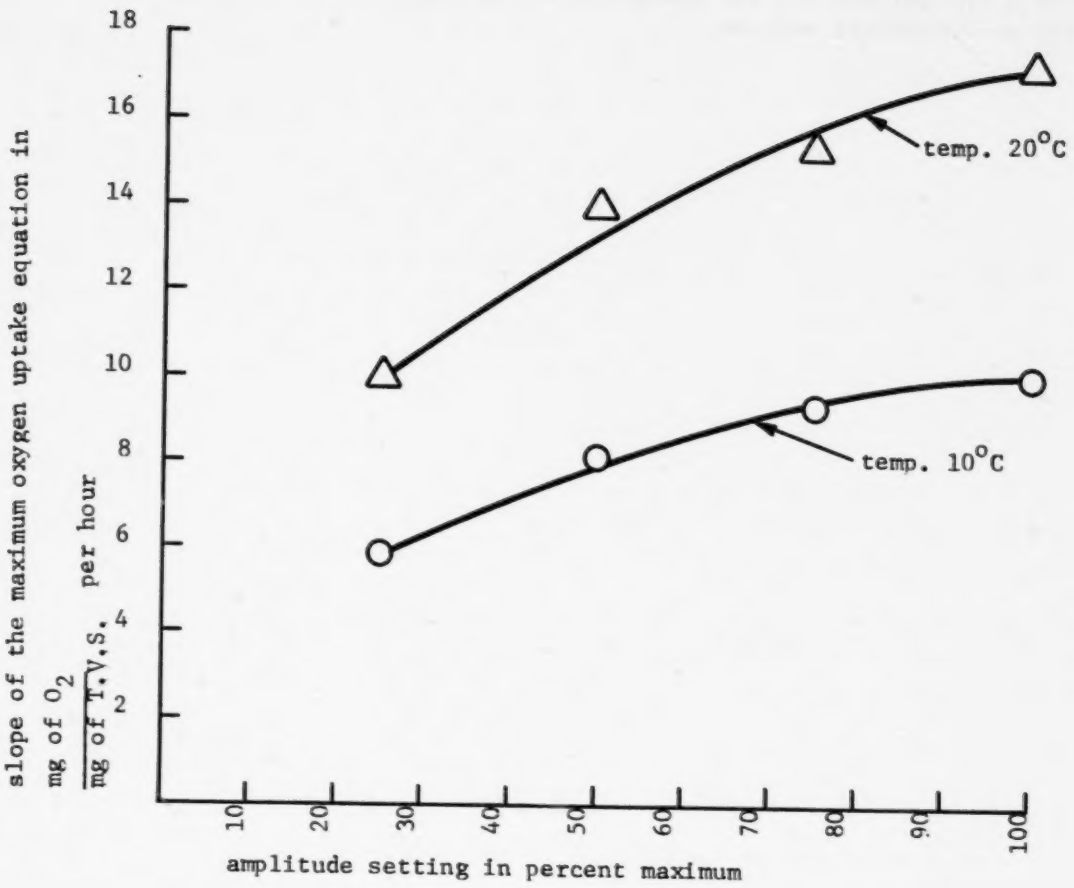

Figure No. 9 - Enveloping Curves Showing Variations in Maximum Oxygen Uptake as a Function of Temperature and Amplitude Setting for Whatcom Sludge.

Sodium Chloride Solutions as a Dilution Medium - Whatcom Creek samples were tested in mediums containing up to 30,000 mg/ℓ of sodium chloride. As in the case of the Squalicum Creek samples, the sodium chloride medium appears to have no significant influence on $\frac{dy}{dt}_o$. However, the total oxygen uptake curve is significantly higher for the salt medium than for the distilled water medium. Figure Number 10 shows a typical Warburg run comparing sodium chloride and distilled water as suspending mediums.

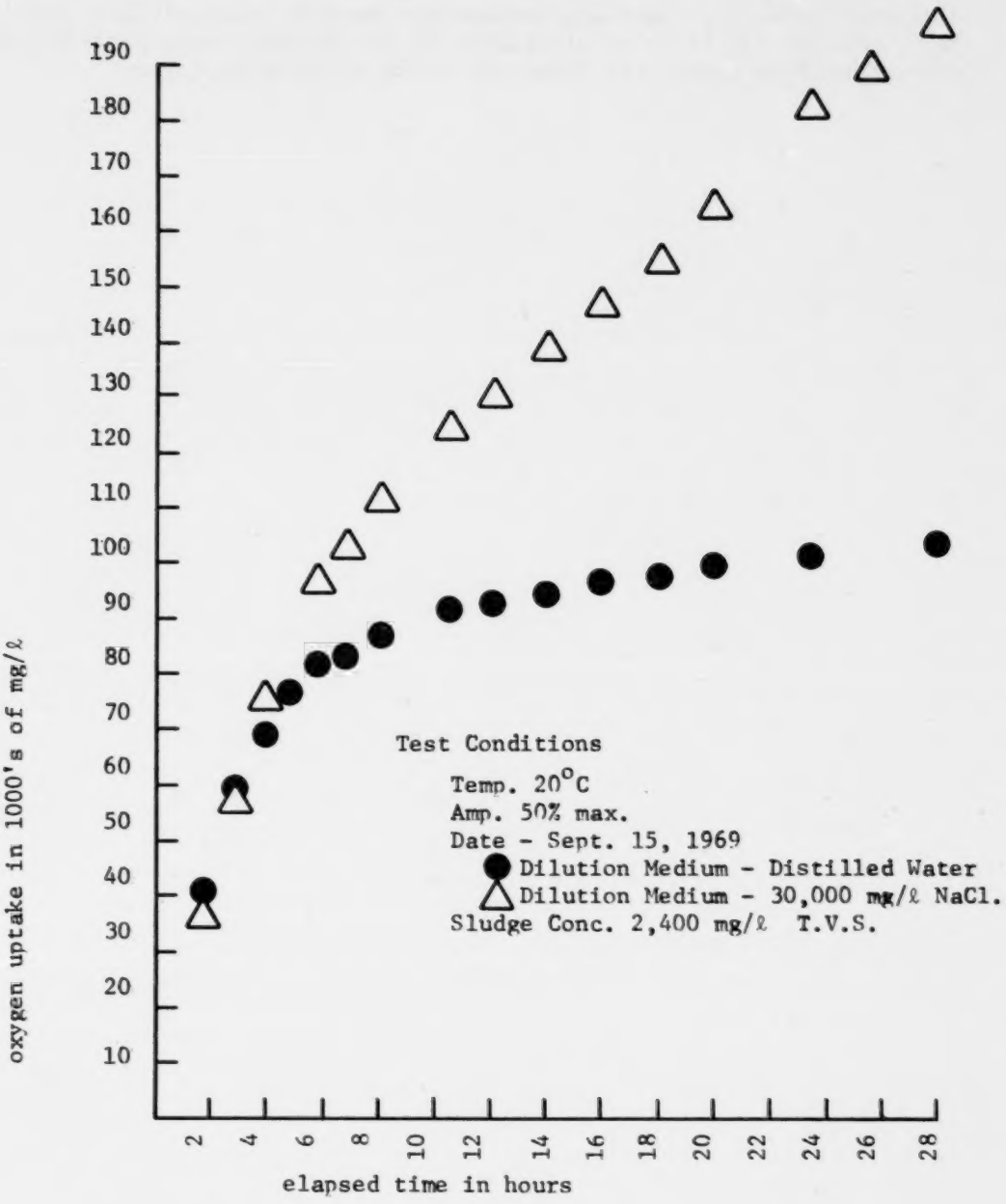

Figure No. 10 - Long Term Oxygen Uptake Analysis for Whatcom Creek Using Sodium Chloride and Distilled Water as Dilution Medium.

B.O.D. Dilution Water as a Suspending Medium - Figure Number 11 is a Warburg analysis run to compare the use of B.O.D. dilution water and distilled water as suspending mediums for Whatcom Creek sludge. The data indicate little or no difference in the oxygen uptake profile for the two mediums during the first six hours of experimentation.

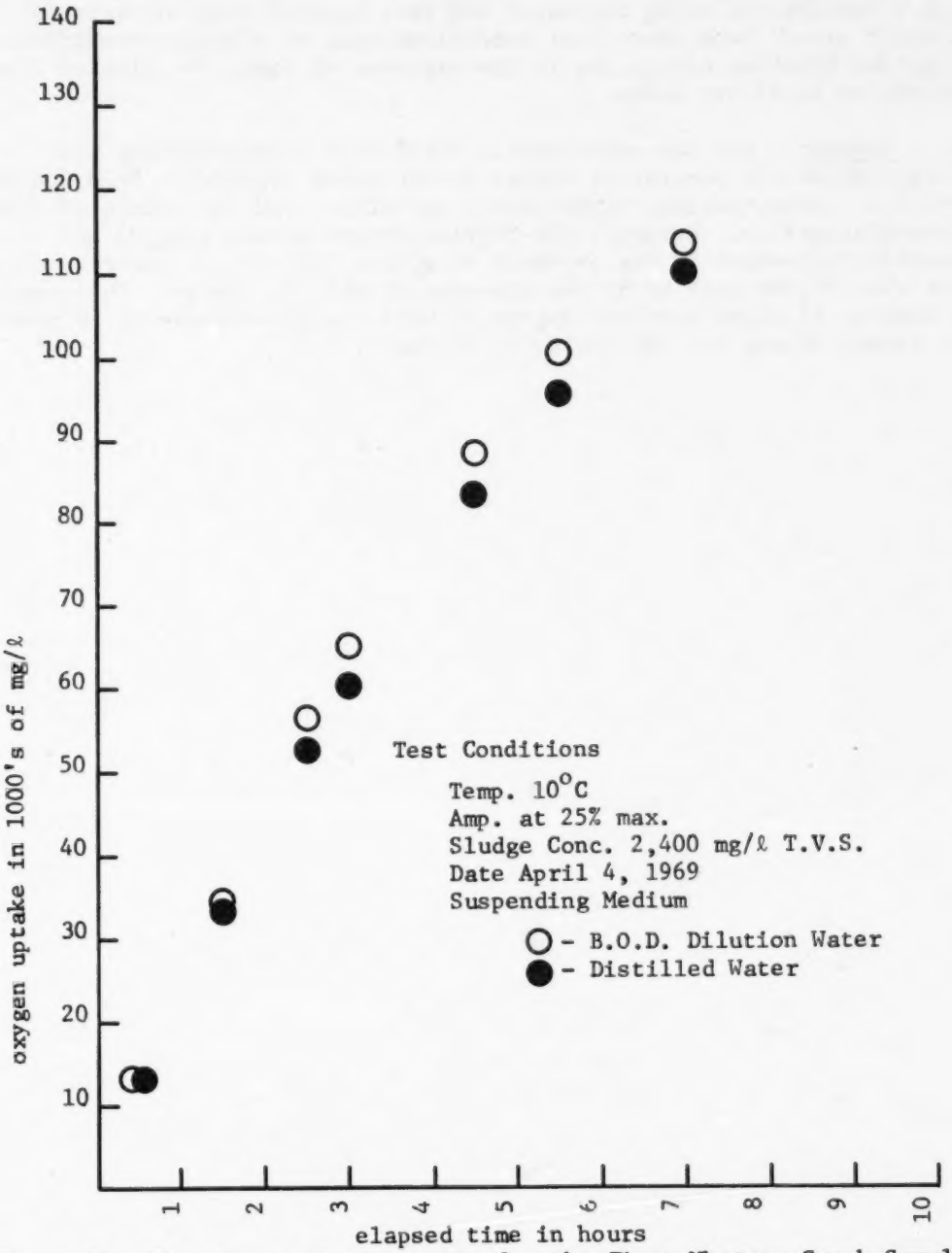

Figure No. 11 - Oxygen Uptake Study for the First Whatcom Creek Sample Using B.O.D. Dilution Water and Distilled Water as Suspending Mediums

Light and Dark Tests - Table Number 6 presents a typical result from a Warburg run using unwrapped and foil wrapped reaction vessels. It would appear from these test conditions that no significant difference in uptake kinetics exists due to the presence of light for elapsed time periods up to eleven hours.

Comment - For the experimental conditions imposed during this investigation the cumulative oxygen uptake curve appears to be a function of T.V.S. concentration, temperature, agitation, and the nature of the suspending medium. However, the initial oxygen uptake rate is not significantly influenced by the presence of sodium chloride in concentrations less than 30,000 mg/ℓ or by the presence of dilution salts. The presence or absence of light does not appear to be a significant factor in measuring oxygen uptake for Whatcom Creek sludge.

Table Number 6 - Oxygen Uptake Studies for Light and Dark Studies on the First Whatcom Creek Sample Using a Distilled Water Medium

Test Conditions	Time (hrs.)	mg/ℓ of oxygen	
		wrapped	not wrapped
Temp. 20°C	0.5	22,181	22,181
Amp. 50% Max.	1.0	45,792	45,792
T.V.S. @ 2400 mg/ℓ	2.0	83,475	83,475
	3.0	107,802	108,756
	4.0	122,351	124,497
	5.0	133,083	134,991
	6.0	139,284	141,192
	7.0	144,054	145,962
	8.0	147,393	150,732
	9.0	150,255	154,071
	10.0	152,163	155,502
	11.0	153,594	157,410

SECTION VII

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Mr. Géza Palotas is deserving of recognition for his efforts in obtaining the necessary laboratory data.

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SECTION VIII

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SECTION IX

GLOSSARY

Agitation - Any external means used to disturb and maintain in suspension sediment material.

Benthic - Refers to that sediment material found on the bottom of rivers, lakes, and estuaries.

Biochemical Oxygen Demand (B.O.D.) - The amount of dissolved molecular oxygen required to satisfy the biochemical reactions involved in the biochmical breakdown of organic material, mg/ℓ.

Bottom Sediments - See Benthic.

Dilution Salts - A solution mixture of phosphate buffer, magnesium sulfate, calcium chloride and ferric chloride used to insure buffering capacity and the presence of necessary trace elements during the biological decomposition of organic compounds.

$\frac{dy}{dto}$ - The initial oxygen uptake rate mg/ℓ/hr.

k - First order rate constant, hr^{-1}.

L_{ULT} - The ultimate oxygen demand attributed to the first order biochemical reactions which occur during the decomposition of organic compounds, mg/ℓ.

Microbial Respiration - That biological oxidation process in which molecular oxygen is used as the oxidizing agent.

Nitrification - The conversion of ammonia to nitrate.

Oxygen Demand - see Biochemical Oxygen Demand.

Reaction Vessel - That component of the Warburg apparatus in which the biochemical reactions occur.

Resuspended Bottom Sediments - Refers to that normally quiescent bottom material that has been disturbed and placed in suspension as a result of agitation.

Seeding - The process of introducing external microorganisms into organic solutions to enhance the presence of biochemical reactions.

Sludge - see Bottom sediments.

t - Elapsed time in hours.

Total Volatile Solids - That amount of the total solids which will ignite at 600°C.

Warburg Cam - Mechanical component of the Warburg appratus which can be used to vary the severity of agitation experienced by the reaction vessel.

Warburg Respirometer - A mechanical instrument that can be used to measure microbial respiration.

y - The amount of oxygen consumed due to microbial respiration, mg/ℓ.

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23 Descriptors (Starred First)

*biochemical oxygen demand
sludge
estuaries
dissolved oxygen
sediments

25 Identifiers (Starred First)

*Warburg respirometer
Bellingham Bay
benthic sludge

27 Abstract

A laboratory study has been conducted to show the application of the Warburg respirometer in evaluating the influence of light, sodium chloride, dilution salts, temperature and agitation on the maximum oxygen uptake rate of disturbed bottom sediments. Experiments were conducted on estuarian benthic material obtained from Bellingham Bay, Washington.

In all experiments the initial oxygen uptake rate was the maximum uptake rate. Results obtained using distilled water as the suspending medium were not appreciably altered due to the addition of BOD dilution salts, or sodium chloride in concentrations less than 30,000 mg/l. The initial uptake rate also appears to be insensitive to light.

Ambient temperatures were varied from 10°C to 20°C and agitation settings were varied from instrument maximum to twenty-five percent of maximum. The Squalicum Creek sample showed variations in initial uptake from 2,000 to 57,000 mg/l of oxygen per hour. The Whatcom Creek sample had a range of from 2800 to 83,000 mg/l of oxygen per hour.

Results indicate that the maximum uptake rate is very sensitive to temperature, degree of disturbance, and the total volatile solids concentration of the benthic material.

Agitation alone was shown to account for at least a ten fold increase in the maximum oxygen demand.

This report is submitted in fulfillment of Project 16070DCD, Contract No. 14-12-481, between the Water Quality Office and Seattle University.

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